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Magnetic Nanostructures as Amplifiers of Transverse Fields in Magnetic Resonance.

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We introduce the concept of amplifying the transverse magnetic fields produced and/or detected with inductive coils in magnetic resonance settings by using the reversible transverse susceptibility properties of magnetic nanostructures [1]. The requirement for the NMR sensor is the high sensitivity to extremely weak radio-frequency fields from the resonant spins, and immunity to the extremely large perpendicular DC magnetic field. This unique requirement makes all magnetic field sensors, other than the inductive coil, generally ineffective.

It has been known for several decades to a very small section of a magnetism community that magnetic nanoparticles have a property that is greatly amplified when a large polarizing magnetic field is applied to them. When a large magnetic field is applied perpendicular to the nanoparticle long axis, the particle becomes very sensitive to the perpendicular small AC field. This is advantageous for magnetic resonance detection, where one needs to amplify the signal in the presence of a large DC field. Another important experimental observation is that these peaks do not depend on frequency in the typical NMR detection band of frequencies. This is critical, as one needs to amplify the magnetic resonance signal at a specific magnetic resonance frequency without having to tune both the magnetic resonance and transverse susceptibility frequencies at the same time. We have tested this property of nanoparticles up to 3MHz, and do not see (or expect) any variation up to frequencies of several giga-Hertz, which is beyond any reasonable nuclear magnetic resonance detection.

Following the initial confirmation of the peaks in reversible transverse susceptibility in oriented magnetic nanoparticle systems [2], we proceeded to model a magnetic resonance system, as shown in Figure 1, by designing micro-coil set-up where one micro-coil contains a thin film of aligned nanoparticles and represents a detector (right side) while the other coil (left side) models the resonant nuclear magnetic spins (of say protons in water). These micro-coils have a width of ~200 micrometers and are about 50 micrometers thick.

Figure 2 shows the pick up signal in the coil on the right due to the field from the coil on the left as a function of the DC magnetic field perpendicular to the page. Again, the peak in the signal occurs at a specific value of the large DC field, demonstrating that in principle the magnetic resonance signal can be amplified if a nanoparticle system can be introduced into a coil. It is interesting to compare this signal to the micro-coil pick up signal if the nanoparticle tape was not inside the coil. One then notices no amplification of the magnetic field detection. One observes that the increase in the signal is about 2%, which does not seem significant, but in fact, one needs to realize that the nanoparticle layer is only approximately 5 microns in thickness, while the coil is about 100 micrometers in thickness. Therefore in principle, one can significantly improve the filling factor inside the coil by filling it with more nanoparticle material, and we demonstrate this experimentally.

We argue that transverse field amplification by magnetic nanoparticles provides not just an improvement in detection sensitivity, but also in magnetic resonance imaging resolution. Since the nanoparticle can in principle be only 5-10 nanometers in size, equivalent imaging spatial resolution would also be possible.

[1] M. Barbic and A. Scherer, Solid State NMR 28, 91 (2005).
[2] M. Barbic, Review of Scientific Instruments 75, 5016 (2004).